AFRL-HE-WP-TR-2001-0168

# UNITED STATES AIR FORCE RESEARCH LABORATORY

# PCBOOM2: Enhancement of PCBOOM Sonic Boom Analysis Program


**Melissa Burn**
**Kenneth J. Plotkin**

**WYLE RESEARCH LABORATORIES**
**2001 Jefferson Davis Highway**
**Arlington VA 22202**


**October 1989**

**Interim Report for the Period June 1989 to November 1989**

20020514 108

*Approved for public release; distribution is unlimited.*

**Human Effectiveness Directorate**
**Crew System Interface Division**
**2610 Seventh Street**
**Wright-Patterson AFB OH 45433-7901**

## NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Air Force Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies and their contractors registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
8725 John J. Kingman Road, Suite 0944
Ft. Belvoir, Virginia 22060-6218

## DISCLAIMER

This Technical Report is published as received and has not been edited by the Air Force Research Laboratory, Human Effectiveness Directorate.

## TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2001-0168

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

**FOR THE COMMANDER**

MARIS M. VIKMANIS
Chief, Crew System Interface Division
Air Force Research Laboratory

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
November 1989

**3. REPORT TYPE AND DATES COVERED**
Interim - June 1989 to November 1989

**4. TITLE AND SUBTITLE**
PCBOOM2: Enhancement of PCBOOM Sonic Boom Analysis Program

**5. FUNDING NUMBERS**
F08635-89-C-0044
PE - 63723F
PR - 3037
TA - 303706
WU - 30370601

**6. AUTHOR(S)**
Melissa Burn
Kenneth J. Plotkin

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Wyle Research Laboratories
2001 Jefferson Davis Highway
Arlington VA 22202

**8. PERFORMING ORGANIZATION REPORT NUMBER**
TN 89-13

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Air Force Research Laboratory, Human Effectiveness Directorate
Crew System Interface Division
Aural Displays and Bioacoustics Branch
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7901

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
AFRL-HE-WP-TR-2001-0168

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

Enhancements have been made to the PCBOOM computer program, described in HSD-TR-88-014. The new program, denoted PCBOOM2, has the following improvements: (1) Focal zone signatures are generated by the latest algorithms from Wyle Laboratories' FOBOOM software. (2) The spectrum and residual shock spectrum of ground boom signatures may be computed. CSEL is then computed from the spectrum. (3) Ground signatures, spectra, and residual shock spectra may be output in graphical or tabular format. (4) The user may directly specify the azimuthal mesh size, thereby permitting faster computations than PCBOOM. (5) Extraneous messages generated during plotting have been eliminated. A copy of this program can be obtained by contacting AFRL/HECB at (937) 255-3605 x423 or downloading the file directly from the public website at www.afcee.brooks.af.mil/EC/noise/noisemodels.htm

**14. SUBJECT TERMS**
sonic boom, model, noise, acoustics

**15. NUMBER OF PAGES**
41

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

This page intentionally left blank.

# PREFACE

The work reported herein was performed under Air Force contract F08635-89-C-0044 during the period from June 1989 to November 1989. The work was conducted under Program Element 63723F, Workunit 30370601, under the direction of the Aural Displays and Bioacoustics Branch of the Air Force Research Laboratory, Wright-Patterson AFB OH. Robert A. Lee was the project monitor.

This page intentionally left blank.

## TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)



## LIST OF FIGURES

## 1.0 INTRODUCTION

PCBOOM[1] is a computer code which computes sonic booms from current U.S. military aircraft. It operates on an MS-DOS-based PC with 640K memory, a hard disk, math coprocessor, and graphics output device (screen and/or plotter). This report documents additions made to the program and represents a supplement to Reference 1. The revised program is denoted PCBOOM2.

The program computes sonic boom by two different methods. One is a partial implementation of Carlson's simplified method,[2] which is suitable for steady flight. The other is a partial implementation of NOAA's TRAPS sonic boom code.[3] That implementation of TRAPS had been modified to include the focal zone algorithms from Wyle Laboratories' FOBOOM code.[4,5] The enhancements presented in this document deal with the TRAPS portion of the program, which is also referred to as the "Ray Trace" method.

The following enhancements have been added to the ray tracing program:

1. The user may specify any arbitrary atmospheric profile, including winds, or can default to the U.S. Standard Atmosphere without winds.

2. Ground signatures of sonic booms are computed, and may be displayed in either graphical or tabular format. The original PCBOOM generated only peak levels. These were output graphically as "smear plots", as described in Reference 1.

3. The energy spectral density and/or residual shock spectrum (see Section 2.3) may be computed and plotted or tabulated. If either of these spectral outputs is selected, then CSEL is computed from the spectrum. The quantity denoted CSEL in the existing PCBOOM output is actually $L_{peak}$ – 26 dB, an approximation which is valid for N-wave sonic booms.

4. The user may specify the azimuthal (PHI) increments used by the program when computing boom across the carpet at each trajectory point. There are two parameters. One is the PHI increment to be used when generating the basic mesh across the carpet. PCBOOM had programmed values of 1 degree for flight altitudes above 15,000 feet, and 2 degrees below. An increment of 5 to 10 degrees is generally

adequate and greatly reduces running time. The second parameter is a refined smaller increment to be used when searching a focal zone. The original code used 1/10 of the basic PHI increment. The new program requests the actual smaller increment.

5. As originally structured, when PCBOOM was run in the ray trace mode, the only output was the smear plots of peak pressure or CSEL, and data to generate these were not retained. All signature and ground ray data are now saved in permanent files. These files may be read and data plotted at any future time, without re-running the ray trace calculations. These files contain all data which would be necessary to generate contour plots, should that output form be required.

6. Some PLOT88 calls in PCBOOM would generate PLOT88 errors 4 and/or 5. PCBOOM would preface these with a message telling the user to ignore them. While this problem was primarily cosmetic, the messages could be confusing. A revised axis generation routine has been supplied which eliminates these occurrences.

To accommodate these changes within a 640K memory limit, changes were made to the program structure. PCBOOM consisted of two modules, SPINONE and PCBM, controlled by batch file PCBOOM.BAT. PCBM has been divided into two sections, and a new program module SIGOUT (which generates signature and spectral output) was written. A new batch file PCBOOM2.BAT, which controls overall operation, has been prepared. The flow of control in PCBOOM2.BAT is now chained from SPINONE to PCBM2. Depending on the action chosen during PCBM2 (Carlson or ray trace), control will either return to SPINONE or will continue through new program PCSMEAR (the second part of old PCBM) on to new program SIGOUT. Except for the new features which are offered, the change is transparent to the user.

Section 2 of this report represents the user's manual, and describes changes encountered by the user during the run stream. Section 3 contains programmer's reference and maintenance information. Described in that section are the changes made to PCBOOM and a complete description of the new program SIGOUT.

## 2.0 USER'S MANUAL

### 2.1 Environment and Installation

PCBOOM2 operates in the same environment as PCBOOM: an IBM PC or compatible (80286 or 80386 preferred) with 640K RAM, a math coprocessor, and a hard disk. The program is distributed on two floppy disks. Disk 1 contains all files necessary to run the program. Figure 1 is a list of files contained on Disk 1. (Files dated earlier than 31 October 1989 are taken unchanged from PCBOOM.) Disk 2 contains source code, and is described in Section 3. To install PCBOOM2, copy all programs on Disk 1 onto the desired subdirectory.

### 2.2 Running PCBOOM2

PCBOOM2 requires user interaction during input and output phases. Most user interaction during the input phase is identical to PCBOOM. Input differences are the added requests for atmospheric profile data and values of PHI increment and the caustic search refined split. These queries appear just after the announcement of estimated processing time. Figure 2 shows the screen after the queries appear. In this case, the standard atmosphere with no winds has been selected. A basic PHI increment of 10 degrees has been entered, with a focus search value of 0.25 degree. These values are boxed in. A good starting value for the basic PHI increment is 5 to 10 degrees. A good range for the focus search increment is 0.1 to 1.0 degree.

Had a non-standard atmosphere been desired, the file names would be entered after the two requests shown in Figure 2. File names may be up to 32 characters long, including path, extension, and punctuation. The files are identical in format to the RAOB and WINDS files required by the original TRAPS program.[3] An excerpt from Reference 3 describing the format of these files is presented here as Appendix A.

Following completion of the calculations (which will take some time*), the messages shown in Figure 3 will appear. Several minutes (depending on the

* The time estimate seen in Figure 2 is not accurate. The program does display status information from which progress can be tracked.

```
 Volume in drive A is PCBOOM2 RUN
 Directory of  A:\

SPINONE  EXE    167948   7-23-88  12:54p
PCBM2    EXE    286683  10-31-89  11:59p
PCSMEAR  EXE    142655  10-31-89  11:59p
SIGOUT   EXE    147799  10-31-89  11:59p
AIRCRAFT DAT       883   3-15-88  12:02p
HELP1    DAT       983   2-26-88  10:19a
HELP10   DAT      1336   3-09-88   6:37p
HELP11   DAT      1547   3-31-88  11:25a
HELP12   DAT       636   3-09-88   6:38p
HELP13   DAT      1188  10-22-88  10:49p
HELP14   DAT       610   5-02-88  11:43a
HELP16   DAT       709  10-22-88  10:50p
HELP17   DAT       394   1-08-88  12:46p
HELP18   DAT      1034  10-24-88   4:12p
HELP2    DAT       903  10-22-88  10:42p
HELP3    DAT       890   2-17-88   5:22p
HELP4    DAT       607   2-17-88   7:41p
HELP5    DAT       567   3-09-88   6:33p
HELP6    DAT       752  10-22-88  10:43p
HELP7    DAT       829  10-22-88  10:46p
HELP8    DAT      1283   2-20-88   1:03p
HELP9    DAT      1552   2-20-88   1:05p
HLP15A   DAT      1185   5-18-88   4:33p
HLPGS1   DAT      1241   3-03-88   3:32p
HLPGS2   DAT      1092   3-21-88   3:08p
HLPIO1   DAT       798  10-24-88   4:09p
HLPIO2   DAT      1424  10-24-88   4:10p
HLPIO3   DAT       714  10-24-88   4:10p
PARAM    DAT        88   5-11-88   3:46p
PCBM     DAT       508   1-08-88   2:44p
PCBOOM   DAT       815  10-25-89   1:17a
PCBOOM2  BAT       202  10-31-89  11:59p
       32 File(s)    435200 bytes free
```

Figure 1. Directory of PCBOOM2 Distribution Disk.

```
WOULD YOU LIKE TO SEE AN EXAMPLE OF THE FLIGHT TRACK (Y/N)? : n
```

| 1:50:26 |
|---|
| THIS FLIGHT TRACK IS MADE UP OF 18 POINTS<br>IT WILL TAKE APP. 144 MINUTES TO COMPLETE<br>(ADD 30 MINUTES FOR EVERY POINT WITH A FOCUS). |

```
Enter atmospheric data file name (ENTER alone for default std. atmos.)

Enter wind profile data file name (ENTER alone for default no winds)

Enter PHI increment for ray tracing (ENTER alone for default 5 degrees)
10
Enter PHI increment for focus search (ENTER alone for default 0.2)
.25
```

Figure 2. Atmospheric Data File and PHI Entry Screen.

```
Opening PCBOOM.dat
Reading from KEEPRAY.
Do you want the smear plot?
```

Figure 3. Initial Display in PCSMEAR.

particular case) will elapse between the "reading KEEPRAY" message and the "Do you want a smear plot?" prompt. This is the beginning of the output phase. If a "yes" response is entered, then smear plots identical to PCBOOM's will be generated.

Following the smear plots, the program will generate a ray/signature file KEEP.BIN and a companion index file INDX.BIN, then enter the new signature output module SIGOUT. Since this module may be entered either as part of a PCBOOM2 run stream or independently, it is described in the next subsection.

## 2.3 SIGOUT

### 2.3.1 Overview and Capabilities

SIGOUT is a signature and spectrum processing module for PCBOOM2. It generates three types of plots: signature, spectrum, and residual shock spectrum. Examples are given in Figures 4, 5, and 6. The data contained in these plots may also be output in tabular format to a file or the printer.

Signature plots, shown in Figure 4, give the waveform pressure versus time. The plot contains various annotation. The top line is a heading similar to that appearing on the smear plots. The second line gives information about the origin and type of ray. The first item, ray number, is a sequential number by which the ray is referenced. (An index, described later, is generated by SIGOUT.) This is followed by the aircraft time and the azimuthal angle PHI. Rtype, the type of ray, is then shown. This is a two-digit number. The first digit may be 1, 2, or 3, representing the following types of boom:

1 – Carpet boom (normal N-wave)
2 – Focus boom (U-wave calculated by FOBOOM algorithms)
3 – Post-focus boom (U-wave via TRAPS Hilbert transform)

The type of boom is also indicated in parentheses at the end of the line. Caution must be taken when interpreting post-focus booms. The use of the Hilbert transform was included in TRAPS as an approximate method of accounting for attenuation in the caustic passage associated with over-the-top secondary booms. Reference 3 contains specific warnings that it is probably not valid this close to a focus.

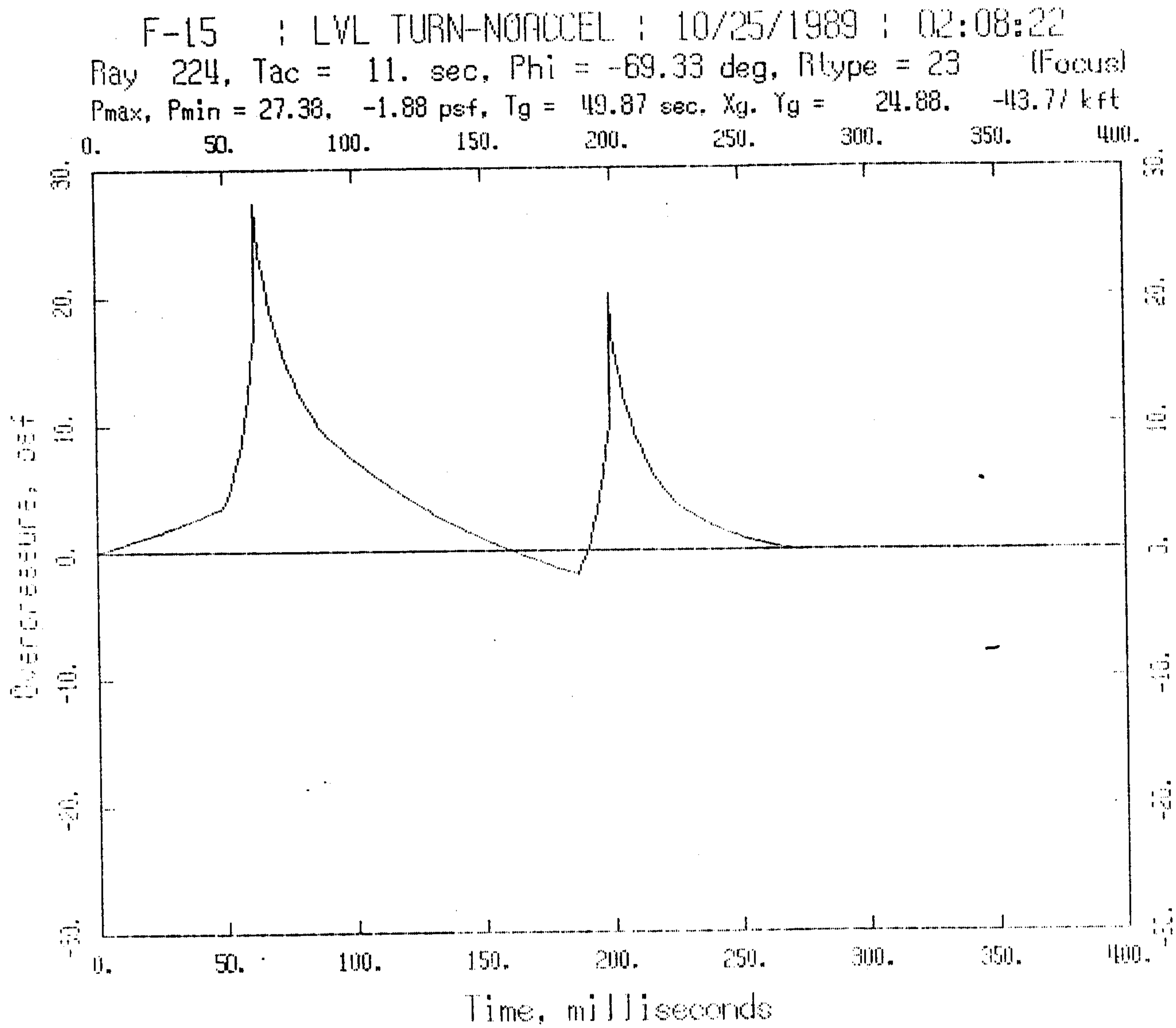


**Figure 4. Typical Signature Plot.**

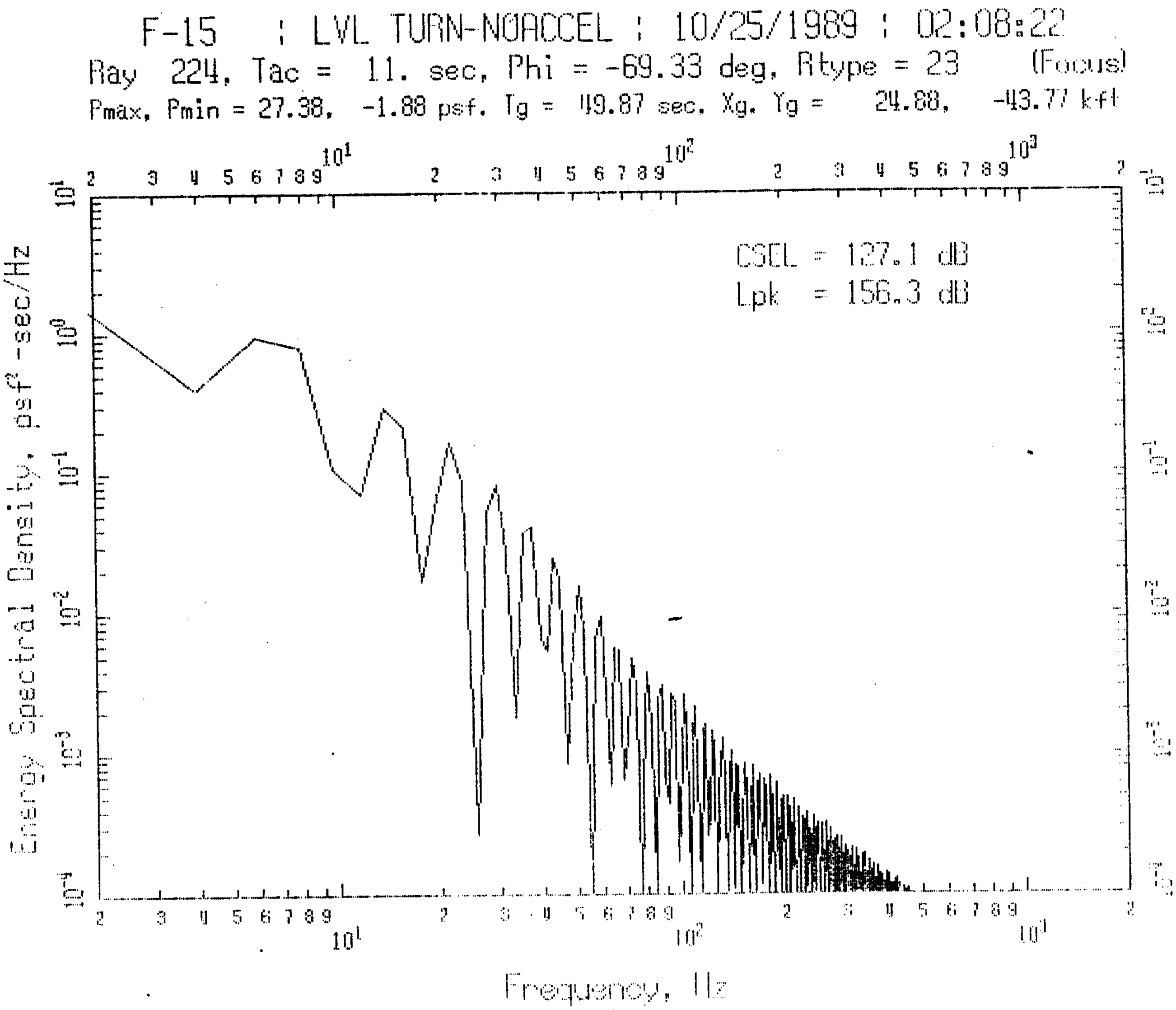


**Figure 5. Typical Spectrum Plot.**

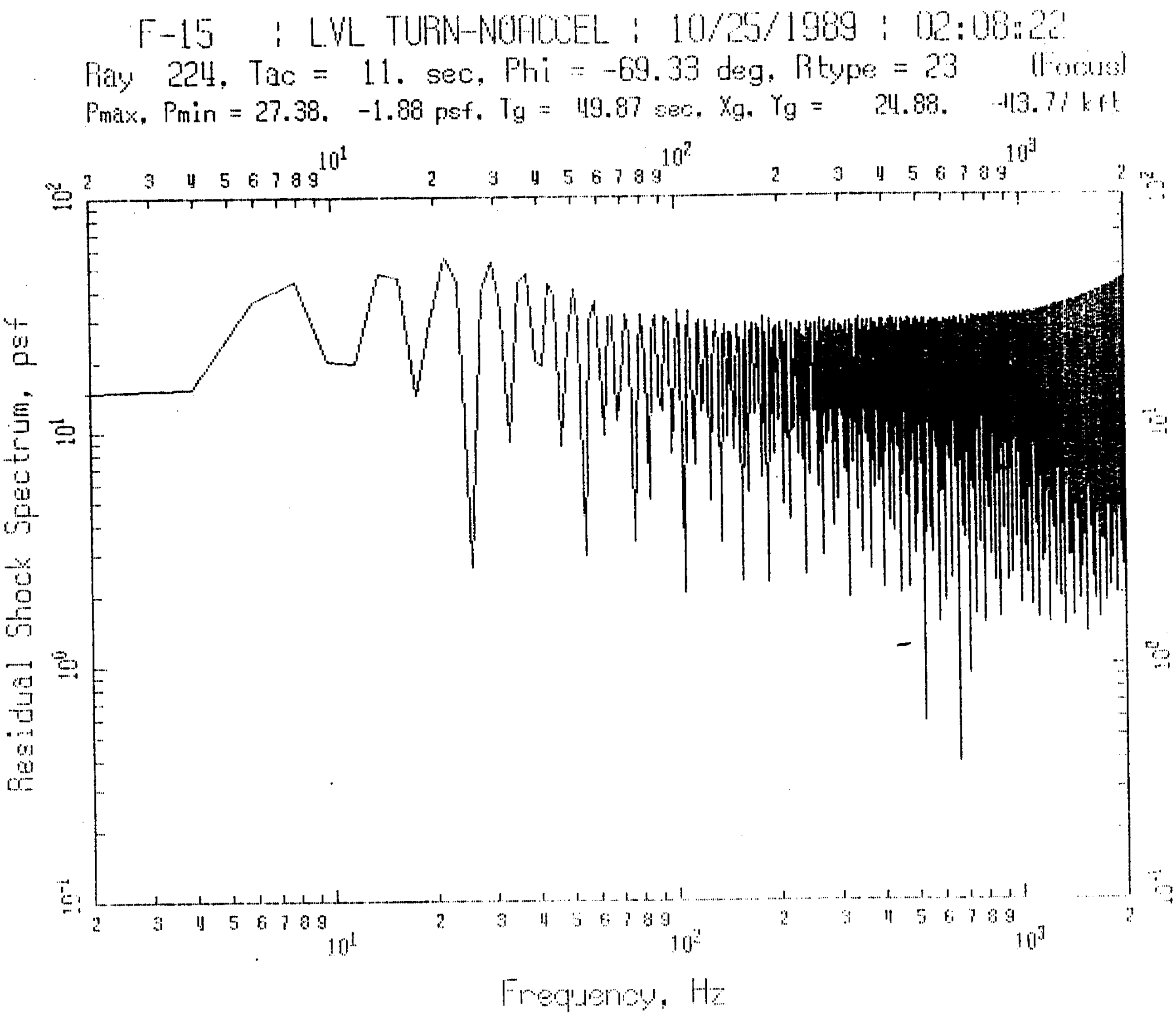


**Figure 6. Typical Residual Shock Spectrum Plot.**

The second digit of Rtype may also be 1, 2, or 3, representing when that signature was computed:

1 – During carpet boom analysis

2 – While searching a caustic region for focus

3 – At or adjacent to a focus

The third line of annotation gives the maximum and minimum pressure, and the time and location of the boom impinging on the ground.

Spectrum plots, as shown in Figure 5, give the energy spectral density of the boom. The same three lines of annotation appear at the top. The peak level (in dB re 20 microPascals) and CSEL are also shown within the figure.

The residual shock spectrum is defined as:[6,7]

$$S(f) = 2\pi f \; |F(f)| \tag{1}$$

where F(f) = Fourier spectrum of impulsive load
f = frequency, Hz

This quantity is used in the evaluation of the response of structures to an impulse. Figure 6 is an example of a residual shock spectrum generated by SIGOUT.

Another key output of SIGOUT is an index of rays. Figure 7 is an example. All rays and their corresponding signatures are stored sequentially in file KEEP.BIN. The order of storage at a given aircraft time is the carpet calculations (Rtype 11 and 31), then rays computed during a caustic search. The index table identifies, at each aircraft time, the ray number range associated with carpet booms (first set of columns) and which are associated with the caustic search (second set of columns). The corresponding PHI values associated with these limiting ray index numbers are also shown. Shown in the last column are the indices and PHI values of all focus (Rtype 23) booms. This index, together with the smear plots, very efficiently identifies rays of interest.

F-15 | LVL TURN-NOACCEL | 10/25/1989 | 00:16:31

| Time | Carpet Booms Ray | Phi | to Ray | Phi | Caustic Booms Ray | Phi | to Ray | Phi | Focus Booms Ray | Phi |
|---|---|---|---|---|---|---|---|---|---|---|
| .0 | 1 | -72.27 | 19 | 72.27 | | | | | | |
| 1.0 | 20 | -72.27 | 38 | 72.27 | | | | | | |
| 2.0 | 39 | -72.27 | 57 | 72.27 | | | | | | |
| 3.0 | 58 | -72.27 | 76 | 72.27 | | | | | | |
| 4.0 | 77 | -72.27 | 94 | 72.27 | | | | | | |
| 5.0 | 95 | -72.27 | 113 | 72.27 | | | | | | |
| 6.0 | 114 | -72.27 | 131 | 72.27 | | | | | | |
| 7.0 | 132 | -72.27 | 149 | 72.27 | | | | | | |
| 8.0 | 150 | -72.27 | 167 | 72.27 | | | | | | |
| 9.0 | 168 | -72.27 | 185 | 72.27 | 186 | -69.32 | 187 | -69.82 | 186 | -72.27 |
| 10.0 | 188 | -72.27 | 205 | 72.27 | | | | | | |
| 11.0 | 206 | -72.27 | 223 | 72.27 | 224 | -69.33 | 225 | -69.83 | 224 | -72.27 |
| 12.0 | 226 | -72.27 | 243 | 72.27 | | | | | | |
| 13.0 | 244 | -72.27 | 261 | 72.27 | 262 | -69.34 | 263 | -69.84 | 262 | -72.27 |
| 14.0 | 264 | -72.27 | 281 | 72.27 | | | | | | |
| 15.0 | 282 | -72.27 | 300 | 72.27 | | | | | | |
| 16.0 | 301 | -72.27 | 319 | 72.27 | | | | | | |
| 17.0 | 320 | -72.27 | 338 | 72.27 | | | | | | |

Figure 7. Typical Index Table.

### 2.3.2 Running SIGOUT

When SIGOUT runs as part of the PCBOOM2 stream, it will read the data it requires from files KEEP.BIN, INDX.BIN, and PCBOOM.DAT, and will show the message shown in Figure 8. If nothing is entered, the program will proceed with those data. If a name is entered, the program will "archive" the data set, renaming the two ..BIN files into name.SIG and name.IND. A new file, name.TIT, will also be generated storing the top title line used on the plots plus information about plot output devices. The name must be a valid file name (no extension) of up to 8 characters. A path may be included, with the total length (path, \s, and name) up to 20 characters. In this case, the name MELMAC has been entered, (boxed in the figure) resulting in archival files MELMAC.SIG, MELMAC.IND, and MELMAC.TIT. MELMAC.SIG is the renamed version of KEEP.BIN, holding the ray trace data and signatures. MELMAC.IND is the index file formerly called INDX.BIN.

Following archive option selection, the output device menu shown in Figure 9 will appear. The selections made here will be archived on the name.TIT file as permanent defaults.

If SIGOUT is run self-standing, an archive file name may be included in the command line, as described in Figure 8. In that case, the screens shown in Figures 8 and 9 will not appear. The program will commence from the following point, which follows after the device selection screen in the no-name case.

SIGOUT will display the number of ray/signature points in the data set, and will offer to show the index (Figure 7) on the screen or print it. No-index or quit options are also offered.

Following the index, the program will enter a cycle of requesting a ray number, asking which type of plot is desired, and to which plot device it should go. Choices are controlled by pressing function keys defined on the screen. In general, "ENTER" is also an option which backs up to the previous level. Pressing ENTER in response to a request for a ray number counts as 0, and backs up to the Index-or-Quit screen.

When the output device selection is made, F9 selects the screen and F10 selects the hard copy plot device. Holding the shift key while pressing F9 or F10 will cause the plot to be generated, then the program will offer to send a table of

```
Default PCBOOM output data set being processed.  You may archive this set
for future access.  For SIGOUT to process an archived set, include its
name on the command line, e.g., SIGOUT MYBOOM, when starting the program.

Enter the name (up to 8 characters, no extension) under which to archive
this data set.  Files name.TIT, name.IND, and name.SIG will be created.
(RETURN alone to not archive it.)
MELMAC
```

Figure 8. Archive Query Screen in SIGOUT.

the data just plotted to either a file or a printer. (A cancel option is included.) When the table option is taken for either type of spectrum, the table includes both spectra. Table printing goes to the default print device PRN. Other devices (e.g., a printer on LPT2) can be accessed by entering their name as if they were files.

The plot output device selection menu includes an option (F5) which presents a menu similar to Figure 9. Choices made at that point will remain in effect during the current run of the program, but will not be saved.

After a ray number is selected, the program will display a table of all signature values. Figure 10 shows an example table. The data are arranged in four pairs of columns, and heading information appears at the top. The "what to plot" choice appears at the bottom. There is no automatic provision to keep the top from scrolling off the screen if there are many points, but the keyboard PAUSE key remains active for manual pausing.

```
Default PCBOOM output data set being processed.  You may archive this set
for future access.  For SIGOUT to process an archived set, include its
name on the command line, e.g., SIGOUT MYBOOM, when starting the program.

Enter the name (up to 8 characters, no extension) under which to archive
this data set.  Files name.TIT, name.IND, and name.SIG will be created.
(RETURN alone to not archive it.)
MELMAC

Screen and Plotter devices must be selected:

1. EGA Screen            6. HP 7475A (LPT2:)
2. CGA Screen            7. HP Laserjet
3. Hercules Screen       8. Epson FX-80, etc.
4. HP 7470A              9. Epson LQ-1500, etc.
5. HP 7475A      10. Device selected in main menus
(Device 10 has IOPORT =  0, MODEL = 41, Scale factor = 1.00)

Enter choices for Screen and Plotter.  Defaults are 1 and 10.
(RETURN alone to accept defaults.)
```

Figure 9.   Default Plot Device Selection in SIGOUT.

Ray 200 Generated at Time = 10. seconds, Phi = 40.00 degrees
Ground intercept at X and Y = 25.02 3.54 kft, Time = 24.08 sec
Peak pressure = 5.39 psf, Ray type 11 (Carpet boom) NPTS = 39

| msec | psf | msec | psf | msec | psf | msec | psf |
|---|---|---|---|---|---|---|---|
| .00 | .00 | 105.30 | 3.10 | 131.60 | .00 | 157.90 | -3.10 |
| 85.80 | .00 | 107.90 | 2.79 | 134.20 | -.31 | 160.50 | -3.41 |
| 85.80 | 5.39 | 110.50 | 2.48 | 136.90 | -.62 | 163.20 | -3.72 |
| 86.80 | 5.28 | 113.20 | 2.17 | 139.50 | -.93 | 165.80 | -4.03 |
| 89.50 | 4.97 | 115.80 | 1.86 | 142.10 | -1.24 | 168.40 | -4.35 |
| 92.10 | 4.66 | 118.40 | 1.55 | 144.70 | -1.55 | 171.10 | -4.66 |
| 94.70 | 4.35 | 121.10 | 1.24 | 147.40 | -1.86 | 173.70 | -4.97 |
| 97.40 | 4.03 | 123.70 | .93 | 150.00 | -2.17 | 176.30 | -5.28 |
| 100.00 | 3.72 | 126.30 | .62 | 152.60 | -2.48 | 177.30 | -5.39 |
| 102.60 | 3.41 | 129.00 | .31 | 155.30 | -2.79 | .00 | .00 |

ENTER: another ray F8: spectrum F9: residual shock spectrum F10: signature

Figure 10. Typical Screen Tabulation of Signature in SIGOUT.

# 3.0 PROGRAMMER'S REFERENCE

## 3.1 Modifications to PCBOOM

### 3.1.1 Atmospheric Inputs

The ability to read atmospheric data represents restoration of a capability from the original TRAPS program.* Subroutine OPENUP and LJUST were replaced in their original positions. Subroutines PTHDIN and WINDIN were restored to their original form. OPENUP was modified to deal only with the atmospheric files, requesting their names from the user. The prompts for the PHI increments (described below) were included in OPENUP.

### 3.1.2 User-Specified PHI Increment

The value of the PHI increment is set in subroutine SCREEN, which generates a table ANG of azimuthal angles at which to compute the boom. In PCBOOM, SCREEN would select the PHI increment based on flight altitude. This has been modified to use the value input by the user.

SCREEN would generate the table of ANG by taking for the first value the negative cutoff limit plus 0.1 degree, then for the second the cutoff limit rounded to the next higher degree toward zero. Subsequent angles would be at PHI increment values above this. The scheme had two problems. First, the positive cutoff limit would not necessarily be included; the routine did not finish with two positive angles corresponding to the initial two. Second, $\phi = 0$ would not necessarily be included in the mesh.

The program was modified so that the regularly spaced mesh would be centered on 0 degree, and each end would include the cutoff angle (adjusted 1 degree toward zero) and the nearest whole degree, rounded toward zero.

---

* The authors would like to thank Dr. Albion Taylor for providing a copy of the latest PC version of TRAPS, from which the required code was copied.

Subroutine GETDLT was modified to supply the user-entered value, rather than divide the current increment by 10. These parameters are passed from OPENUP to SCREEN and GETDLT via COMMON /AZMINC/ . These three routines have been grouped into source file MODSUB.

### 3.1.3 Focus Signatures

The current version of subroutine FOCALP was installed. The scaling of the boom signature entering FOCALP was adjusted to correspond to that required by FOCALP. It was assumed that the location of this signature relative to the focus, and the ray/caustic curvature value, were correctly calculated.

### 3.1.4 Signature Output

#### 3.1.4.1 Retrieval and Output of Signatures

PCBOOM calculated signatures at the ground intercept of each ray. Once signatures were calculated, only the peak pressure (or CSEL, calculated from the formula $CSEL = 101.6 + 20 \log_{10} P_{pk}/psf$, regardless of signature type) was retained. The signature itself tended to be abandoned. Part of the signature output modification consisted of finding where in the code the signatures were, determining (and correcting, as necessary) their scaling status, and communicating them to a master file.

All pertinent ray information and boom signatures were written to a master file KEEPRAY. This file is opened on Unit 20 and is patterned after existing scratch file CLIBRY, but with signatures added. KEEPRAY is written by a modified version of subroutine STORE. Signatures are communicated to STORE via COMMON /PX/ . This block has been installed in subroutines EXTRPR, FOCAL, FOCMAP, RBRAYS, RTRACE, SIGNUP, SIGPRT, and STORE. The COMMON contains variable IFLAG (identified as Rtype in SIGOUT output), which has now been deleted from STORE's argument list. This affects calls from RTRACE, EXTRPR, RBRAYS, and STORE.

Subroutine RBRAYS has been substantially modified so that the signatures are properly indexed when caustic rays are sorted.

### 3.1.4.2 Structure of KEEPRAY

This file stores all results from the TRAPS portion of PCBOOM2. Figure 11 is an excerpt from the top, showing the heading and records from three rays, with their signatures.

The first line holds four integer counters:

NREC = number of records (lines) in file KEEPRAY
NSETS = number of ground intercept and signature data sets
OPREC = starting record number of caustic overpressures
NFP = number of flight track points

The second line holds a text description of the flight case. The data sets start on the third line and continue up to the line indicated by OPREC. A single data set consists of one record, or line, of ground intercept data (13 items) followed by as many lines as necessary to list the element pairs of the signature arrays.

The ground intercept line includes:

IFLAG = ray type code;

11 – carpet boom
12 – pre-focus boom processed by FOCMAP
13 – pre-focus boom processed by FOCAL
23 – focus boom processed by FOCAL
32 – post-focus boom processed by FOCMAP
33 – post-focus boom processed by FOCAL

T0 = time in seconds; flight track point minus 1
X0 = x-coordinate of aircraft
Y0 = y-coordinate of aircraft
Z0 = aircraft altitude
TG = time, in milliseconds, of ray propagation to ground
XG = x-coordinate of ground intercept
YG = y-coordinate of ground intercept
PHI = azimuthal angle of ray
P = pressure at ground
CSEL = C-weighted Sound Exposure Level
M = Mach number
NPTS = number of points (elements) in signature array

```
      7579      1210      7577      18
   LVL TURN-NOACCELXXXXXXXX 0NOLOCATION  F-15  XXXXXXXX          .00
11    .00  -1967.      0.    3048.    62.10   8728. -17601.  -72.269   93.2262  107.3877   1.9963 29
 1     .0      .00        185.2       .00     185.2     93.23     187.1     90.28     192.1     82.76
 6  197.0    75.23        201.9     67.71     206.8     60.19     211.8     52.66     216.7     45.14
11  221.6    37.62        226.5     30.09     231.4     22.57     236.4     15.05     241.3      7.52
16  246.2      .00        251.1     -7.52     256.1    -15.05     261.0    -22.57     265.9    -30.09
21  270.8   -37.62        275.8    -45.14     280.7    -52.66     285.6    -60.19     290.5    -67.71
26  295.5   -75.23        300.4    -82.76     305.3    -90.28     307.2    -93.23        .0       .00
11    .00  -1967.      0.    3048.    56.32   7715. -15910.  -72.000  100.4124  108.0327   1.9963 29
 1     .0      .00        176.6       .00     176.6    100.41     179.7     95.28     184.4     87.34
 6  189.1    79.40        193.8     71.46     198.6     63.52     203.3     55.58     208.0     47.64
11  212.7    39.70        217.5     31.76     222.2     23.82     226.9     15.88     231.7      7.94
16  236.4      .00        241.1     -7.94     245.8    -15.88     250.6    -23.82     255.3    -31.76
21  260.0   -39.70        264.8    -47.64     269.5    -55.58     274.2    -63.52     278.9    -71.46
26  283.7   -79.40        288.4    -87.34     293.1    -95.28     296.2   -100.41        .0       .00
11    .00  -1967.      0.    3048.    41.48   5138. -11536.  -70.000  126.5213  110.0402   1.9963 31
 1     .0      .00        151.3       .00     151.3    126.52     153.4    121.80     157.6    112.43
 6  161.7   103.06        165.9     93.69     170.0     84.32     174.2     74.95     178.3     65.59
11  182.4    56.22        186.6     46.85     190.7     37.48     194.9     28.11     199.0     18.74
16  203.2     9.37        207.3       .00     211.5     -9.37     215.6    -18.74     219.8    -28.11
21  223.9   -37.48        228.1    -46.85     232.2    -56.22     236.4    -65.59     240.5    -74.95
26  244.6   -84.32        248.8    -93.69     252.9   -103.06     257.1   -112.43     261.2   -121.80
31  263.3  -126.52           .0       .00        .0       .00        .0       .00        .0       .00
```

Figure 11. Excerpt From Top of KEEPRAY.

The signature data consists of pairs of time and pressure values. A signature data line starts with an integer telling the index of the first pair on that line. So, a leading 16 on a line indicates that the next item is the sixteenth element pair in the signature array. Then five element pairs are given in the order time (i), pressure (i), time (i+1), pressure (i+1), . . . , time (i+4), pressure (i+4). If NPTS is not an even multiple of 5, the last line is padded with zeroes to finish it out.

3.1.4.3 Split of PCBM

Module PCBM contained the Carlson model, the ray tracing model, and the smear plot routine. To accommodate the enhancements, the smear plot routine for ray trace cases has been placed in a separate program. This was a natural place to split the program, since data required for the smear plots were stored in scratch file CLIBRY which was read in at this point. File KEEPRAY contains all data necessary for the smear plots (including all CLIBRY data), as well as signature analysis.

The modified main program is denoted PCBM2. At the point where subroutine SMEAR_PLOT would be called following TRAPS calculation, PCBM2 terminates. The batch stream carries it into PCSMEAR, which is described in Section 3.1.5. When PCBM2 reaches the normal Carlson termination, it ends with a return code of 3, which signals the batch stream to return control to input menu module SPINONE. Smear plots for the Carlson case are still generated within PCBM2.

3.1.4.4 Axis Generation

PLOT88 axis generation and labeling routines will, in some cases, automatically scale tic labels and append a $10^n$ annotation to the axis label. To avoid the $10^n$ appearing on the right and top axes, PCBOOM would write a long blank string as the label, forcing the $10^n$ (if any) off the page. This resulted in messages regarding PLOT88 errors 4 and 5.

An axis-generating routine WYLEAX, which does not scale tic labels, has been supplied. This replaces calls to PLOT88 routines STAXIS and AXIS, as appropriate. These calls are located in modules I01 and I02, which have been renamed I01W and I02W, respectively. All associated messages have been deleted. Routine WYLEAX is supplied as object module WYLEAXIS.OBJ.

### 3.1.5 PCSMEAR

Program PCSMEAR effectively replaces the last portion of PCBM. It reads file PCBOOM.DAT (SPINONE output) exactly as does PCBM2. It then reads KEEPRAY via new subroutine RD_20. RD_20 performs the same actions on KEEPRAY as RD_CLIBRY did on CLIBRY. Additionally, it reads the signatures and writes all data out in binary form to file KEEP.BIN, with index file INDX.BIN.

Following RD_20, the program calls SMEAR_PLT. That routine is unchanged. Generating the smear plot is optional, as described in Section 2. If the option is declined and it is later desired to generate smear plots, PCSMEAR can be run by itself provided files PCBOOM.DAT and KEEPRAY have not been overwritten by subsequent runs.

When PCSMEAR ends, the batch stream runs program SIGOUT, described in Section 3.2.

### 3.1.6 Miscellaneous Changes to PCBM Source Code

While modifying PCBM to enhance the ray tracing, data storage, and spectrum plotting capabilities, mionor changes were introduced. Program modules and segments of code which had been commented out or orphaned were removed. this was done to reduce program size and improve running efficiency. These changes are documented by comments within the code.

## 3.2 SIGOUT

### 3.2.1 Structure and Subroutines

Figure 12 is a subroutine hierarchy chart for SIGOUT. Not shown are calls to SPINDRIFT or PLOT88 library routines. The main program module SIGOUT controls most of the user interaction. The role of each subroutine is described below, in alphabetical order. Detailed documentation for each routine is contained within the source code.

#### 3.2.1.1 ACWT

This routine provides the value of C-weighting, as a ratio, for a given input frequency. It is taken directly from MDBOOM,[8] a version of FOBOOM prepared for McDonnell Douglas Corporation.

#### 3.2.1.2 BLOCK DATA

This routine contains default values of various data items. The text and parameters for the plot output devices are contained here.

#### 3.2.1.3 FFT

This routine performs a complex fast Fourier transform, using the Cooley-Tukey algorithm. This routine was taken from MDBOOM.

#### 3.2.1.4 GETFIL

For a given ray index number, this routine reads the corresponding records from KEEP>BIN and passes them back via a COMMON block.

#### 3.2.1.5 LOUDNS

This routine controls calculation of spectra. For a given signature, it obtains a line power spectrum from SPECT1. It normalizes this to energy spectral density. The residual shock spectrum is also prepared, and CSEL is computed from the energy spectrum. This is a modified version of an MDBOOM module.

#### 3.2.1.6 PCBTIT

This routine controls the startup phase of the program. The interaction illustrated in Figures 8 and 9 is generated here. The action SIGOUT takes is determined by whether or not there is a name included on the command line calling it.

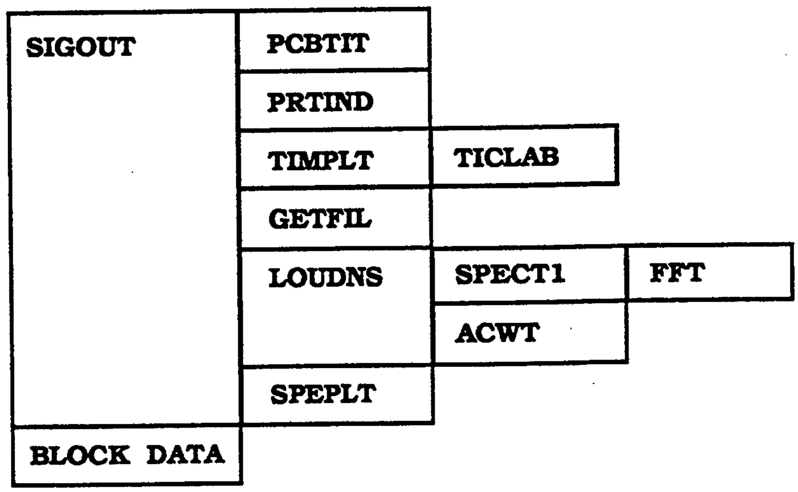


Figure 12. SIGOUT Subroutine Hierarchy Chart.

3.2.1.7 PRTIND

This routine generates the index table shown in Figure 7.

3.2.1.8 SPECT1

This routine, taken from MDBOOM, obtains the energy spectrum of a signature. The signature is redistributed onto a regular mesh with a power-of-2 length, as required by FFT. The program is set for a 2 kHz bandwidth, and current dimensions will accommodate up to a 2-second signature length. The Fourier transform obtained from FFT is converted to an energy spectrum.

3.2.1.9 SPEPLT

This routine generates the spectrum and residual shock spectrum plots, as illustrated in Figures 5 and 6.

3.2.1.10 TIMPLT

This routine generates the signature plots, as illustrated in Figure 4.

3.2.1.11 WYLEAX (x, y, ctext, nchar, axlen, angle, first, delta, annhgt, tihgt, ticlng, ndeca)

This FORTRAN-callable routine generates annotated axes, as described in Section 3.1.4.4. The arguments are presented here because source code is not available. The arguments correspond to all of those required by PLOT88 routine AXIS, followed by all (except exphgt) required by STAXIS. Definitions are contained in the PLOT88 manual, and the effect (except for the absence of scaling) is exactly as if STAXIS and AXIS were called. This routine is also used in PCBM2 and PCSMEAR.

3.2.2 SIGOUT Maintenance

There are two potential maintenance items. One is the choice of plot devices. The menu is limited, specifically because it reads the selection made in SPINONE from unlimited choices. The default parameters and text are defined in BLOCK DATA.

The second potential maintenance item is if spectra are required for signatures longer than 2 seconds or for frequencies above 2 kHz. Dimensions and parameters in LOUDNS and SPECT1 would have to be adjusted accordingly. Note that aircraft available in the program are not expected to generate signatures as long as 2 seconds. Also, given the zero thickness shock structure generated by this program, spectra even at 2 kHz are probably not realistic.

### 3.3 Software Compilation and Linking

Distribution Disk 2 contains all sources (except WYLEAX) required to build programs PCBM2, PCSMEAR, and SIGOUT. Routine WYLEAX is supplied in compiled form as WYLEAXIS.OBJ. Module SPINONE is taken directly from the original PCBOOM; consult Reference 1 if it is necessary to rebuild that.

All compilation and linking is performed with Microsoft FORTRAN Version 4.01. In general, source modules should be compiled by the command:

```
FL /Gt /c /4Yb name.for
```

PCBM2 may not fit into 640K if compiled this way. For PCBM2 source modules, the /4Yb switch (which enables error trace-back) should not be used. Depending on exact memory available, it may be necessary to optimize for size via the /0s switch. The command for minimum size is:

```
FL /Gt /c /0s name.for
```

Program modules PCSMEAR and SIGOUT do not have this size problem.

The /Gt switch is necessary: the link step may fail if it is not included.

Directory LINKBATS on Disk 2 contains batch files which control the linking of PCBM2, PCSMEAR, and SIGOUT. All three programs require the PLOT88 library. Program SIGOUT requires the SPINDRIFT library. The batch files assume that these libraries are located in the default LIB subdirectory assigned to FORTRAN.

## REFERENCES


1. Bishop, D.E., Salvetti, A., and Sediman, H., "PCBOOM Computer Program for Sonic Boom Research", HSD-TR-88-014, October 1988

2. Carlson, H.W., "Simplified Sonic Boom Prediction", NASA TP 1122, March 1978.

3. Taylor, A.D., "The TRAPS Sonic Boom Program", NOAA Technical Memo ERL ARL-87, July 1980.

4. Plotkin, K.J., and Cantril, J.M., "Prediction of Sonic Boom at a Focus", AIAA Paper 76-2, January 1976.

5. Plotkin, K.J., "Sonic Boom Focus Conditions Due to Tactical Air Operations", Wyle Research Report WR 84-8, February 1984.

6. Sutherland, L.C., "Sonic and Vibration Environments for Ground Facilities – A Design Manual", Wyle Laboratories Research Staff Report WR 68-2, March 1968.

7. Sutherland, L.C., "The Fourier Spectra of Transient Excitations and Maximum Residual Responses of an Undamped Single-Degree-of-Freedom System – A Generalized Approach", Wyle Laboratories Technical Memorandum TM 67-4, 1967.

8. Plotkin, K.J., and Desai, V.R., "MDBOOM and MDPLOT Computer Programs for Sonic Boom Analysis", Wyle Research Report WR 88-7, September 1988.

# APPENDIX A

## RAOB and WINDS File Descriptors From TRAPS Documentation

## RAOB File - Pressure/Temperature/Height Profile

At many points in the program, values are required for temperature, pressure and density at various heights, as well as their first and second derivatives with respect to height. This information is provided through a hydrostatically consistent form of interpolation within an internal table. The information in this table is supplied from the U. S. Standard Atmosphere Table, 1976 ([COESA:1976], referred to below as SAT76), or from user-supplied data, or both, and is controlled by the data set linked to FORTRAN unit 10. On IBM 360/370 computer systems using OS, this is the data set defined by DDNAME FT10F001.

If this data set is empty or if the first card contains the keyword "STANDARD" in columns 1-8, then the SAT76 table will be used. Otherwise, the user may provide data from rawinsonde observations or from rocketsondes using the format in Figure B.1:

Figure B.1
Data Format for RAOB File

| | | | | |
|---|---|---|---|---|
| card 1 | up to 72 characters for title | | | |
| card 2 | pressure unit | temperature unit | temperature unit | altitude unit |
| card3-cardnn | <pressure> <values> | temperature values | <dewpoint> <values> | <height> <values> |
| | <END> | | | |

Note: the brackets <> denote fields which are optional (see below).

The keyword parameters for units in card 2 may be selected from Table B.1. If omitted (blank), default units will be assumed as follows:

Pressure---MB
Height---Geopotential Meters
(Heights assumed Geopotential unless specified Geometric)
Temperature/Dewpoint---if a unit is provided for only one of these, the same unit will also be used for the other. If both are missing, Celsius will be assumed.

Numeric data from the rawinsonde or rocketsonde observations must be entered according to the following rules:

(1) Data must be entered in increasing order of altitude.
(2) At all levels, temperature must be supplied, and

Figure B.2
Example of data for RAOB File

```
RAOB JFK-CHH-KWAL COMBINED 0000Z, FEB 11,1979
MB      C       C       GPM
1022.   -9.5    -20.5   8.
1000.   -11.1   -20.1
850.    -23.1   -24.6
718.    -31.5   -36.2
700.    -30.3   -36.3
540.    -27.7   -43.7
500.    -31.5   -45.5
433.    -39.3   -51.3
400.    -41.3
300.    -48.5
250.    -48.3
200.    -45.3
175.    -43.3
150.    -46.9
135.    -46.3
100.    -54.5
80.     -50.1
70.     -54.1           18250.
50.     -53.7           20410
30.     -52.3           23710.
20.     -50.3           26340.
15.     -46.3
5.      -42.7           35555.
2.      -30.6           41695.
1.      -20.2           47025.
.4      -18.3           53690.
        -14.            55511.
        -7.             57476.
        -18.            59439.
        -20.            61401.
        -22.            63362.
END
COMMENT -- SAMPLE OF RAOB DATA
```

either pressure or height. Dewpoint is optional, but should be entered if available.

(3) For at least one level, both pressure and height must be supplied.

(4) The input reader will not read beyond the optional end statement; subsequent cards may be used for documentation if desired.

(5) There is an upper limit of 79 levels allowed for RAOB input.

(6) Dewpoint must never be greater than Temperature.

The above rules are designed to follow as closely as possible the nature of actual measurements made in practice. For radiosondes, these are pressure, temperature, and dewpoint; height is not measured but separately calculated. By contrast, rocketsondes normally report only height and temperature. One of each type of sounding may be combined to form a single data set, using pressures from one and heights from the other.

## Action taken by Input Reader Routine

The input reader routine handles the data in essentially* the same way that a RAOB is "worked up". First, a virtual temperature is calculated from the temperature and dewpoint information at each level. This is the temperature at which dry air would have the same pressure-density dependence as the actual air. Starting from the lowest level at which both temperature and pressure are provided, the routine proceeds to calculate heights of adjacent levels where pressures are known, or pressures of those levels where only heights were given. Except for the starting level, if both pressure and height are given for a level, the height is ignored but will be printed out with the calculated height for purposes of comparison. When differences of more than 100 meters are found, the input data should be rechecked.

If all dewpoints are missing at and above a certain level, then the air will be considered dry at and above that level. Otherwise, if there are dewpoints supplied above and below but not at a given level, dewpoint information will be interpolated. If there is dewpoint information above but not below or at a given level, the lowest available dewpoint will be used.

For altitudes above those for which the user has supplied data, heights and temperatures will be provided from SAT76. Pressures are then calculated from the nearest user-supplied datum level in the same manner as if these were user-supplied height/temperature data. The top limit to this interpolated data is 130,247 gpm. Instead of switching to a smooth profile above 86km as in SAT76, we continue to apply the conventions in force at lower altitudes; namely, linear temperature dependence on geopotential height within each layer. We have approximated the curved profile above 86km in SAT76 by a sequence of closely spaced height/temperature values.

Below the user supplied data, we have inserted an extra pressure-temperature point from SAT76, corresponding to the entry at 5000gpm below sea level. This will provide automatic interpolation below the user-supplied data if needed.

---

*There is a slight difference in that we use an interpolation algorithm for temperature which is linear with geopotential height rather than pressure. Although this agrees with SAT76, it is not general practice. Usually data points are chosen so closely that the difference is small.

## WINDS File - Height/Direction/Speed Profile

Wind speeds and their derivatives with respect to height have a considerable effect on the ray trajectories and the resulting overpressures. Although winds are usually determined on the same balloon flights as the information given in the RAOB section, they are not generally reported at the same levels or in the same terms. Accordingly, the wind data, if any, will be supplied by the user on a separate data set linked to FORTRAN unit 15. On IBM 360/370 computer systems using OS, this is the data set defined by DDNAME FT15F001.

If this data set is empty or if the first card contains the keyword "NOWINDS" in columns 1-8, then the air will be assumed to be calm; a wind speed of zero will be used throughout. Otherwise, the user may provide data from rawinsonde observations or from rocketsondes using the format in Figure B.3:

Figure B.3
Data Format for WINDS File

| | | | |
|---|---|---|---|
| card 1 | up to 72 characters for title | | |
| card 2 | height unit | DEG | speed unit |
| card3-cardnn | height values | direction values | speed values |
| | <END> | | |

Note: the brackets <> denote fields which are optional.

The keyword parameters for units in card 2 may be selected from Table B.1. If omitted (blank), default units will be assumed as follows:

Height -- Geopotential Meters
(Heights assumed Geopotential unless specified Geometric)
Direction -- Degrees
(Note- units keyword will be ignored since the only unit allowed is degrees from which the wind is blowing).
Speed -- Knots

The following rules hold for numeric data entry in this data set:
(1) Data must be entered in increasing order of altitude.
(2) Missing data will be assumed to be zero. Thus, Height data should never be missing.

Figure B.4
Example of data for WINDS File

```
WINDS JFK-CHH-KWAL COMBINED 0000Z, FEB 11, 1979
GMM      DEGREES  KNOTS
8.       310.     15.
119.     305.     22.
1219.    305.     30.
2439.    320.     43.
4881.    285.     94.
5796.    285.     106.
7018.    275.     79.
10380.   275.     73.
13277.   270.     56.
14970.   285.     37.
15981.   265.     37.
20410.   290.     8.
22000.   230.     2.
23710.   080.     13.
26340.   090.     24.
30000.   060.     14.
33000.   055.     17.
35555.   080.     49.
41000.   030.     16.
41695.   270.     17.
42000.   330.     16.
47025.   350.     17.
53690.   250.     43.
56000.   255.     103.
58000.   250.     140.
60000.   260.     146.
62000.   265.     144.
64000.   260.     148.
65000.   260.     144.
68000.   260.     81.
70000.   260.     81.
72000.   280.     79.
END
SAMPLE OF WINDS DATA
```

(3) The input reader will not read beyond the optional "END" statement; subsequent cards may be used for documentation if desired.
(4) There is an upper limit of 79 levels allowed for WINDS input.
(5) There is no need for the heights of levels in the WINDS File to be the same as in the RAOB File.

## Action taken by Input Reader Routine

The input reader routine reads the user-supplied data and converts them to internal units. In addition, it adds extra levels at geopotential altitudes of 5000 meters below sea level and 130,274 meters above, at which the winds are zero.

The program will interpolate the wind speeds and directions linearly with respect to geopotential height. This was considered more realistic than the alternative of interpolating the wind components, although the interpolation of wind directions poses special programming problems. In each layer between two levels for which the wind speed is non-zero, so there exists a definite wind direction at both ends, a rate of direction change with height is chosen for which the total direction change over the layer is no more than 180 degrees. If a layer is bounded by a level at which the speed is zero, so there is no definite direction at that end, no turn rate can be calculated. In such a case, there may be an adjacent layer for which a turn rate does exist; if so then that turn rate will be used. If not, then a turn rate of zero will be used.

After the input reader has processed the RAOB and WINDS files, it combines them into a single table, using all the levels from each file. This table is used to supply meteorological data to the main program on demand.